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ABSTRACT

When people say that what they hear is "over their heads," they are describing a severe information-based complexity (I-BC) problem. They cannot understand what is said because some of the information needed is missing, contaminated, and/or costly to obtain. Students often face these I-BC problems, and teachers often exacerbate them. Yet listeners can provide feedback that will help the speaker give needed information to reduce I-BC problems. However, careful statistical analysis of the feedback is required before speakers can interpret all the data that listeners provide. Causal diagrams, like those used in marketing and social science research, can be used to indicate how "observable" or "hearable" responses from listeners can be used to infer what is wrong and what is right with presentations on difficult topics. (Appended to the document are: (1) seven pages of causal diagrams; (2) a table of definitions; (3) a table of estimation equations; (4) a flow chart of applications of informational theory to speech communication; and (5) two pages of references.) (SKC)

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Measurement of Information-Based Complexity in Listening

8th Annual ILA Convention, 1987

Walton B. Bishop*

Summary

When people say that what they hear is "over their heads," they are describing a severe information-based complexity (I-BC) problem. They cannot understand what is said because some of the information needed is missing, contaminated, and/or costly to obtain.

Students often face these I-BC problems, and some teachers exacerbate them. Yet, the response listeners make can provide the information speakers need to reduce I-BC levels. Professor J. F. Traub, of Columbia University, introduced the I-BC concept at the 1985 IEEE International Symposium on Information Theory as something basic to computer technology, but likely to be useful in many other areas. The author discussed the applications of I-BC to human communication at the 1986 IEEE ISIT.

This paper argues that listeners are best qualified to provide the information needed to reduce their own I-BC problems. This information is in the form of feedback, as described by the author at the 1984 ILA Convention. But careful statistical analyses of the feedback are required before speakers can interpret all the data that listeners provide.

Causal diagrams, as used in marketing and social science research, are used in the paper to indicate how "unobservable" or "hearable" responses from listeners can be used to infer what is wrong and what is right with presentations on difficult topics with which listeners are not familiar.

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Measurement of Information-Based Complexity in Listening

Walton B. Bishop

Information theory can be applied to human communication, but to be fully effective, it must be modified to include uses made of information possessed by an individual before receiving a message. (Bishop 1986b; McMillan, 1953).

The prior information possessed by every listener has a profound effect upon the interpretation he or she gives to each message heard. When the information heard deals with a scientific concept, or another form of technical material, the task of comprehending often becomes an information-based complexity (I-BC) problem.

Traub (1985a, 1985b) defined information-based complexity as the intrinsic difficulty of solving a problem concerning which information needed is missing, contaminated, and/or costly to obtain. He was concerned with how computers face these problems, but he noted that they occur in many other areas. Gardner (1985) described similarities between computer operations and how we believe the brain operates, and Bishop (1986a, 1986b) discussed how I-BC problems arise in human communication.

The speaker who underestimates or overestimates the capabilities of his or her listeners seldom communicates well. The measurement of information-based complexity in listening should enable speakers to estimate more correctly their listener's

capabilities by giving speakers a better understanding of the comprehension problems faced by their listeners.

Listeners, the most common human receivers of information, have excellent opportunities to measure and/or demonstrate the effectiveness of modified forms of information theory. Informally, listeners can observe the effects of giving speakers and prospective speakers various types of information. A simple form of this experimentation consists of providing "guidance" feedback (Bishop, 1986a), which should help speakers learn how to improve their messages.

Formally, listeners can provide both feedback and other types of data needed by researchers to determine valid indicators of unobservable parameters that affect auditory communication. One of the most important of these unobservable parameters is the prior information a listener has available for use in comprehending messages.

Guidance feedback can be given by a listener who does not understand what he or she hears, as well as by one who does. Guidance feedback, unlike the "directive" feedback described by Barker (1971, p. 119), requires no value judgements. Its purpose is to help the speaker learn more about the listener's needs, rather than to reward or punish him or her. It thus is devoted entirely to helping perform the most important function of feedback--improving "the accuracy of understanding" (Barker, 1978, p. 63).

The understanding of a message may be improved by information provided by a prospective listener before a speaker begins trying to convey a message to him or her, as well as while the message is being sent, and after it has been received. Most speakers try to adjust their presentations to the capabilities of their audiences. In the absence of information about these capabilities, mistakes are often made. And even with this information, the effects it will have upon message comprehension cannot always be predicted.

Until recently, many human phenomena, such as the comprehension of a message, have not been included within the domain of science. Some scientists considered the use of scientific methods on the study of human phenomena unethical or dehumanizing. Others considered human phenomena unsuitable for scientific study, because they appear to be "relatively unobservable, subjective, complicated, and spontaneous" (Woelfel, & Fink, 1980, p. 2).

We now have new ways of observing and measuring human phenomena. The Galileo system (Gillham & Woelfel, 1977; Woelfel & Fink, 1980), for example, determines how subjects perceive relationships that affect communications. And we have computer programs that can tell us some of the places we may have made mistakes in model specification (Jöreskog, & Sörbom, 1983), as well as analyze large quantities of data.

Listener contributions to the information-theoretic study of auditory communication can reduce I-BC problems faced by listeners

who try to understand scientific messages. These contributions, in other words, can reduce the difference between what a listener knows and what a speaker believes he or she knows.

Psychologists disagree concerning how much we can learn about how the human brain processes information (Greeno, 1983; Phillips, 1983; Shavelson, 1983), but this does not prevent scientists from making and testing hypotheses concerning effects that can be produced by various causes (Gardner, 1985; Woelfel, & Fink, 1980).

Engineers like to consider the human brain to be something like a black box, the internal functioning of which must be deduced by examining the outputs produced in response to various carefully selected inputs. These studies produce many black box models that represent brain-like functions. See for example Hopfield and Tank (1985), and Sternberg (1985).

The engineer's approach agrees closely with that used by social scientists, who study human behavior using causal analysis (Bagozzi, 1980; Blalock, 1985a, 1985b; Kenny, 1979). Little modification of their causal diagrams is required to make them fit I-BC problems arising in human communication.

Figure 1 provides a typical example of a causal diagram in which observable responses from listeners might be used to indicate what takes place in the process of reducing an I-BC problem faced by the listener. This causal diagram is only a slightly-modified version of that used to describe I-BC problems for human communication in general (Bishop, 1986b).

Figure 1 (a) provides a diagram of hypothesized relationships among unobservable variables in the auditory communication process. The parameters that appear in Fig. 1 are defined in Table I.

The relationships in the causal diagram of Fig. 1 are based on the assumptions that:

1. The speaker's conception of the listener's capabilities ξ_1 affects the complexity of each message as perceived by the listener η_1 .
2. The listener's capabilities ξ_2 affect the listener's comprehension η_2 of each message.
3. The ambient noise level and/or number of distractions ξ_3 present may affect the listener's comprehension η_2 .
4. The listener's perception of a message's complexity η_1 and the listener's comprehension η_2 affect each other to form what is called a "nonrecursive" relationship (Bagozzi, 1980, p. 72) in which a change in perceived complexity η_1 can affect comprehension η_2 and vice versa.

The unobservables (unobservable variables) of Fig. 1 (a) may produce numerous observable effects as well as unobservable ones. Some of the possible observable effects are illustrated in Figures 1 (b) and 1 (c).

In Fig. 1 (b), the observable effects for exogenous (independent) variables ξ_1, ξ_2, ξ_3 are labeled $x_1, x_2, \dots, x_6$. These effects are called "indicators," because they indicate

information about variables that cannot be observed directly.

The indicators for the speaker's conception of listener's capabilities ξ_1 are the topic chosen x_1 , the elocution used x_2 , and the vocabulary used x_3 . Other indicators, such as the sentence structure used, the eye contact exercised, the visual illustrations used, and the time devoted to difficult aspects of material presented might easily have been added. (The example presented here is illustrative only--No attempt has been made to make it complete).

For simplicity, only two indicators for the listener's capabilities ξ_2 are provided in Fig. 1 (b), but both the listener's educational status x_4 and his or her level of involvement with the topic x_5 can easily be assessed. Many additional indicators could have been selected. For example, the listener's grade-point-average, his or her method of taking notes, and his or her demeanor might also have been used.

Indicator x_6 , which seems to be the same as the unobservable variable ξ_3 , illustrates a special case that can easily occur in causal analysis (Bagozzi, 1980, p. 174). This apparent paradox can be explained by noting that the number of distractions or noise level present may produce different effects on the comprehension of different listeners. Studies have shown that distractions can increase, as well as decrease, the persuasiveness of messages (Petty, Wells, & Brock, 1976). Thus, the possibility that distractions might increase, as well as decrease, comprehension

should be considered.

The random errors $\delta_1, \delta_2, \dots, \delta_5$ indicate errors that may occur in measurements for $x_1, x_2, \dots, x_5$ respectively. The absence of an error, indicated by setting δ_6 equal to zero is possible because no other measurement is available in the diagram to contradict the value obtained for x_6 .

Figure 1 (c) shows three typical indicators y_1, y_2, y_3 for the unobservable message complexity as perceived by the listener η_1 and five indicators $y_4, y_5, \dots, y_8$ for the unobservable listener's comprehension η_2 . (See the definitions of these parameters in Table I). The random errors $\epsilon_1, \epsilon_2, \dots, \epsilon_8$ indicate the measurement errors for $y_1, y_2, \dots, y_8$ respectively.

Note that none of these indicators include a statement from the listener that he or she understands the message. Listeners may easily believe they understand a science concept or a message when they do not. Perhaps one indicator could be the failure of a listener to say he or she does not understand. When listeners say they do not understand a concept, they are usually correct, but they may not always volunteer this information when it is true.

In all causal diagrams of the type used here, there may be some variances that are not fully explained by the measurements and/or the model used. These variances are represented by $\mathcal{J}_1$ for η_1 and $\mathcal{J}_2$ for η_2 in Fig. 1.

Figure 2 shows how structural equations are derived to determine the validities and reliabilities of the observed variables. Figure 3 shows how structural equations for theoretical relationships or causal effects among unobservable parameters can be derived. Figure 4 provides the fundamental matrices used by the LISREL[®] program. The estimation equations resulting from this analysis are provided in Table II. The computer will solve these equations to give the coefficients of causality needed to evaluate the model's effectiveness in representing the communication processes hypothesized.

High coefficients of causality designate strong causal relationships, and low coefficients designate weak or negligible ones. By determining the coefficients produced when different indicators and different causal diagrams are used, the best indicators for I-BC can be found.

The search for good indicators may include both voluntary and unintentional inputs from listeners and/or prospective listeners. It might even include analyses of film made with a hidden camera, if researchers can solve the ethical problems involved.

Once we learn how to measure the I-BC faced by typical listeners, we can determine the effects of different methods of presenting any information of concern. The method that produces the smallest I-BC in listeners should produce the best comprehension of the information being presented.

Information obtained from causal analysis should help the

speaker determine how to reduce a listener's information-based complexity and thus reduce the need for continued analysis by means of feedback as indicated in the information-theory diagram of Fig. 5.

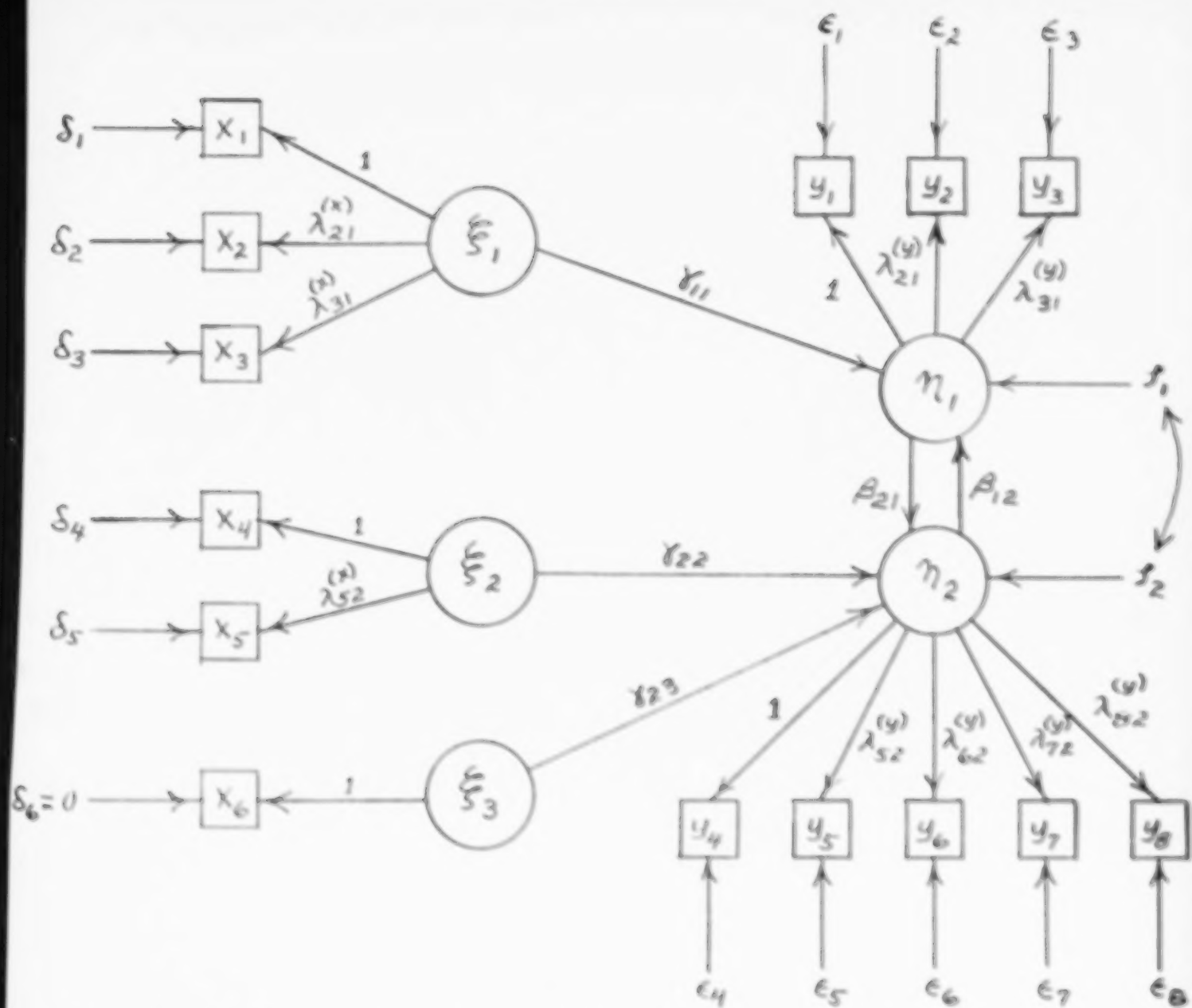


Fig. 1 Information-Based Complexity Causal Diagram

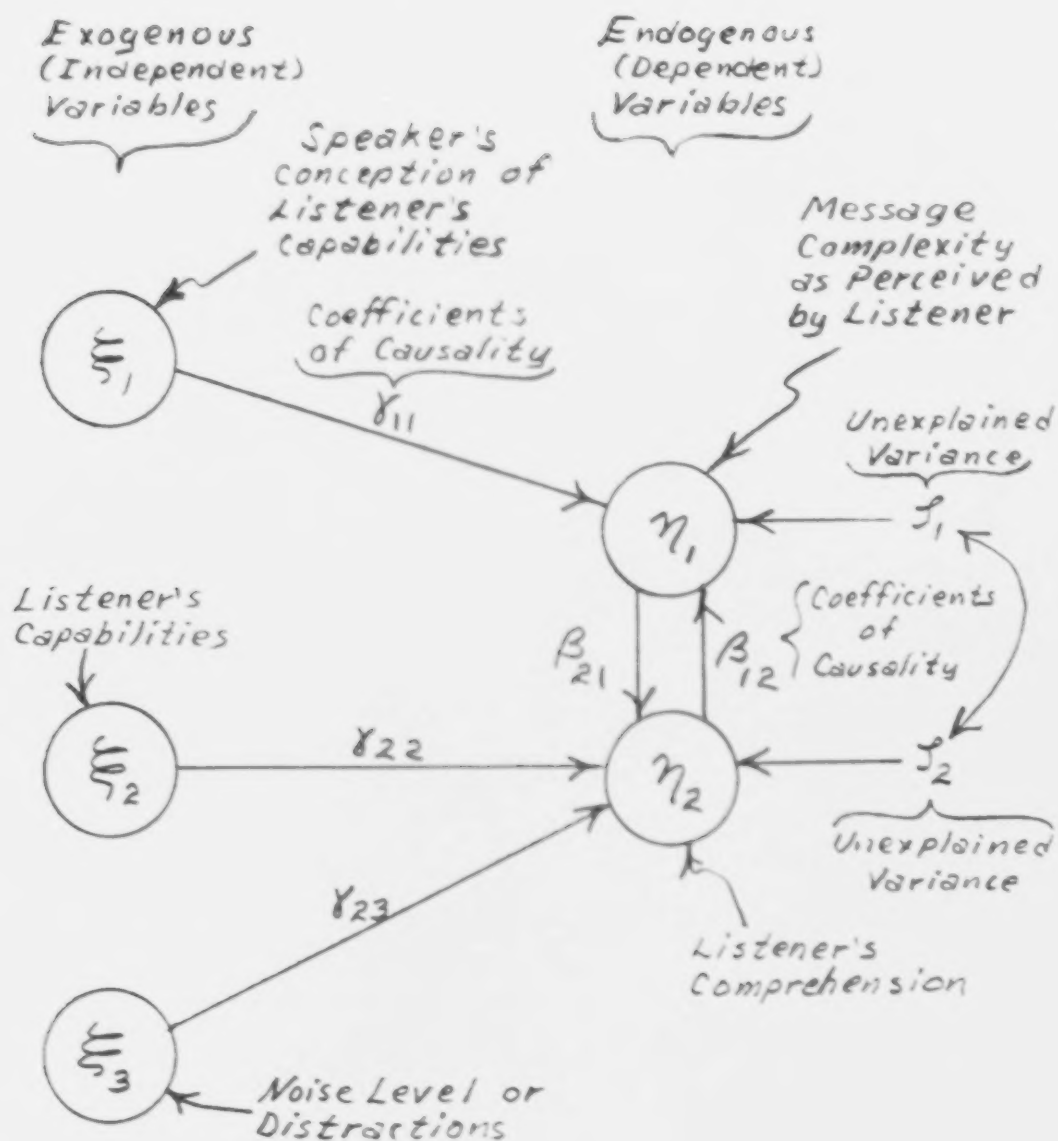


Fig. 1(a) Theoretical Model of I-BC Problem

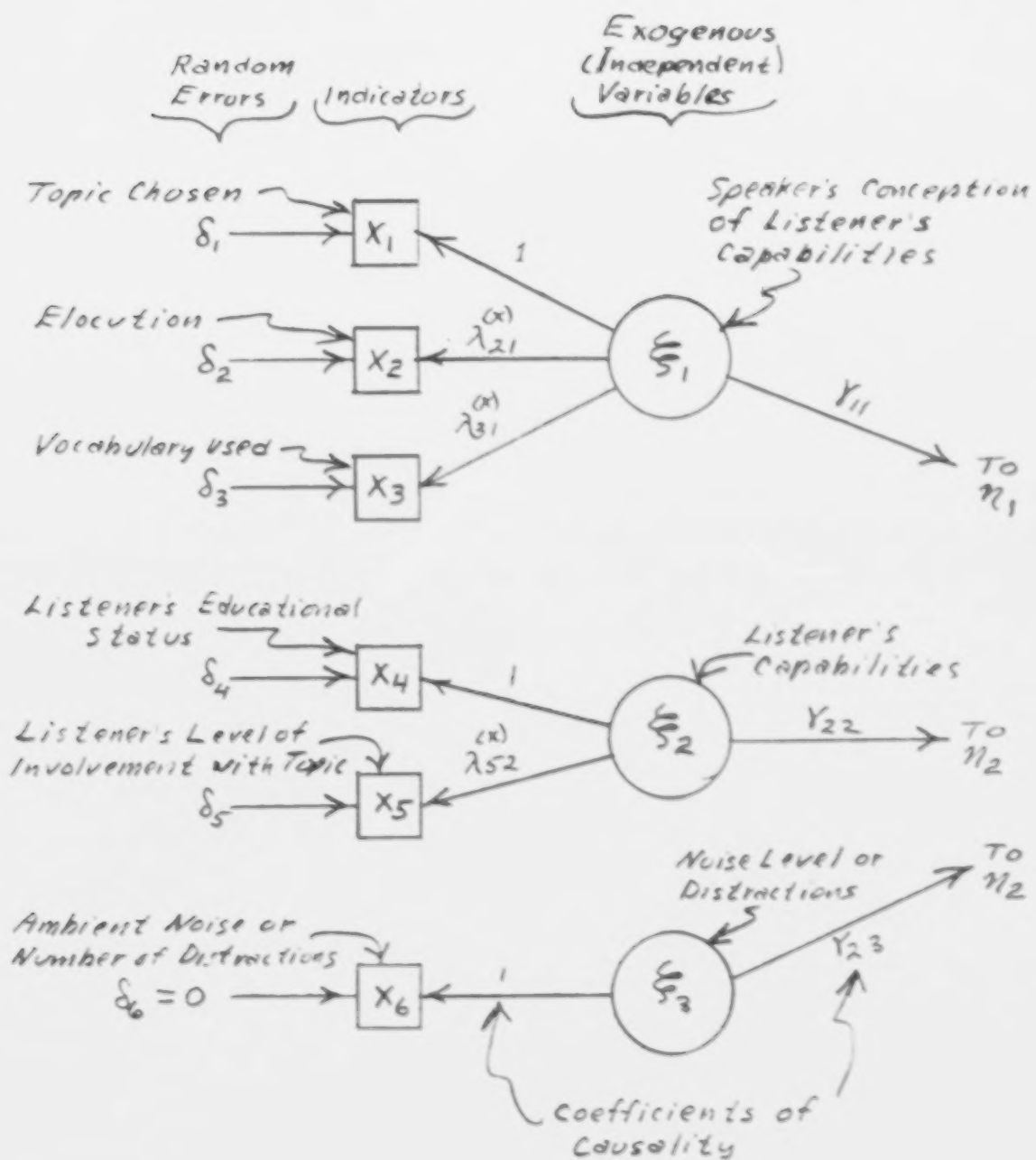


Fig. 1(b) Exogenous Variables and Their Indicators

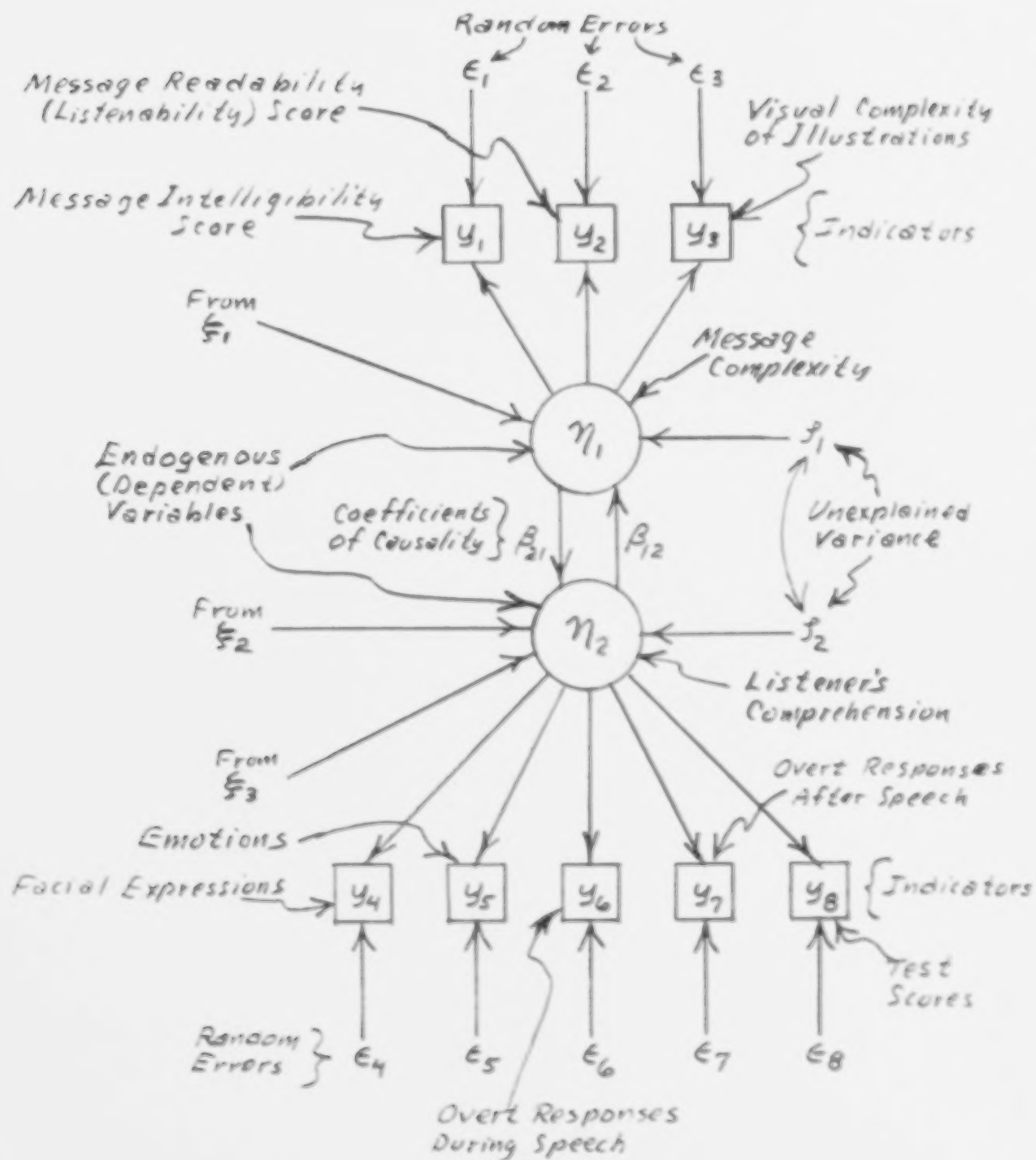


Fig. 1(c) Endogenous Variables and Their Indicators

(a) Structural Diagram and Equations for Exogenous Variables in Measurement Model



(b) Structural Diagram and Equations for Endogenous Variables in Measurement Model

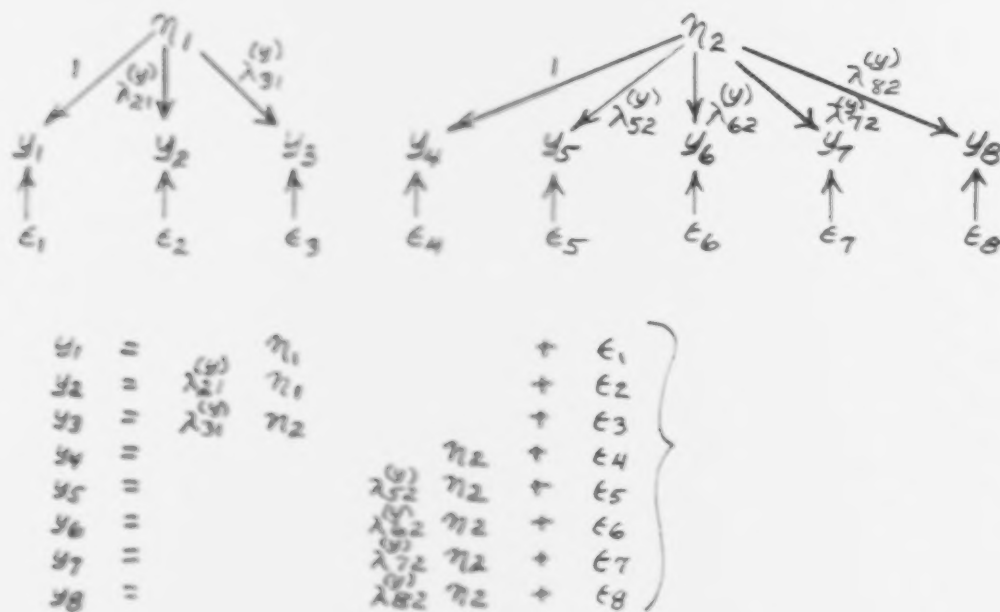
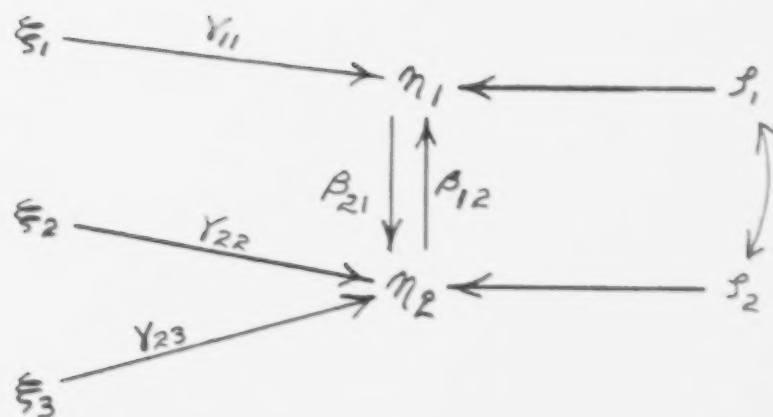


Fig. 2 The Measurement Model

Structural Diagram and Equations for
Theoretical Model



$$\left. \begin{aligned} \eta_1 &= \beta_{12} \eta_2 + \gamma_{11} \xi_1 + \epsilon_1 \\ \eta_2 &= \beta_{21} \eta_1 + \gamma_{22} \xi_2 + \gamma_{23} \xi_3 + \epsilon_2 \end{aligned} \right\}$$

Fig. 3 The Theoretical Model

(a) The Four Measurement-Model Matrices

$$\underline{\Lambda}_y = \begin{pmatrix} 1 & 0 \\ \lambda_{21}^{(y)} & 0 \\ \lambda_{31}^{(y)} & 0 \\ 0 & 1 \\ 0 & \lambda_{52}^{(y)} \\ 0 & \lambda_{62}^{(y)} \\ 0 & \lambda_{72}^{(y)} \\ 0 & \lambda_{82}^{(y)} \end{pmatrix} \quad \underline{\Lambda}_x = \begin{pmatrix} 1 & 0 & 0 \\ \lambda_{21}^{(x)} & 0 & 0 \\ \lambda_{31}^{(x)} & 0 & 0 \\ 0 & 1 & 0 \\ 0 & \lambda_{52}^{(x)} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\underline{\Phi}_t = \begin{pmatrix} \sigma_{e_1}^2 & & & & & & & \\ 0 & \sigma_{e_2}^2 & & & & & & \\ 0 & 0 & \sigma_{e_3}^2 & & & & & \\ 0 & 0 & 0 & \sigma_{e_4}^2 & & & & \\ 0 & 0 & 0 & 0 & \sigma_{e_5}^2 & & & \\ 0 & 0 & 0 & 0 & 0 & \sigma_{e_6}^2 & & \\ 0 & 0 & 0 & 0 & 0 & 0 & \sigma_{e_7}^2 & \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \sigma_{e_8}^2 \end{pmatrix} \quad \underline{\Phi}_e = \begin{pmatrix} \sigma_{e_1}^2 & & & & & & & \\ 0 & \sigma_{e_2}^2 & & & & & & \\ 0 & 0 & \sigma_{e_3}^2 & & & & & \\ 0 & 0 & 0 & \sigma_{e_4}^2 & & & & \\ 0 & 0 & 0 & 0 & \sigma_{e_5}^2 & & & \\ 0 & 0 & 0 & 0 & 0 & \sigma_{e_6}^2 & & \\ 0 & 0 & 0 & 0 & 0 & 0 & \sigma_{e_7}^2 & \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \sigma_{e_8}^2 \end{pmatrix}$$

Symmetric

(b) The Four Theoretical Model Matrices

$$\underline{B} = \begin{pmatrix} 0 & \beta_{12} \\ \beta_{21} & 0 \end{pmatrix} \quad \underline{\Gamma} = \begin{pmatrix} \gamma_{11} & 0 & 0 \\ 0 & \gamma_{22} & \gamma_{23} \end{pmatrix}$$

$$\underline{\Xi} = \begin{pmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \end{pmatrix} \quad \underline{\Psi} = \begin{pmatrix} \sigma_{\xi_1}^2 & \sigma_{\xi_1 \xi_2} \\ \sigma_{\xi_1 \xi_2} & \sigma_{\xi_2}^2 \end{pmatrix}$$

Fig. 4 The Eight Fundamental Matrices

Table I. Definitions of Terms in Causal Diagrams

Exogenous and Endogenous Variables

ξ_1 = speaker's conception of listener's capabilities

ξ_2 = listener's capabilities

ξ_3 = noise level or distractions

η_1 = message complexity as perceived by listener

η_2 = listener's comprehension

Indicators for ξ_1 :

x_1 = topic chosen

x_2 = elocution

x_3 = vocabulary used

Indicators for ξ_2 :

x_4 = listener's educational status

x_5 = listener's level of involvement with topic

Indicator for ξ_3 :

x_6 = ambient noise or number of distractions

Random Errors

δ_i = random errors in measuring x_i , for $i = 1, 2, \dots, 6$

ϵ_j = random errors in measuring y_j , for $j = 1, 2, \dots, 8$

Table I (Continued)

Indicators for η_1 :

y_1 = message intelligibility score (Includes vocabulary used)

y_2 = message readability score (A listenability or comprehensibility test is needed).

y_3 = visual complexity of illustrations

Indicators for η_2 : (Mostly in form of guidance feedback)

y_4 = facial expressions (surprise, frown, smile, boredom)

y_5 = emotions (laughter, tears)

y_6 = overt responses during speech (applause, booing, departure)

y_7 = overt responses after speech (comments concerning interestingness, clarity, changes needed).

y_8 = test scores (essay, objective, practical)

Unexplained Variances

f_1 = unexplained variance of η_1

f_2 = unexplained variance of η_2

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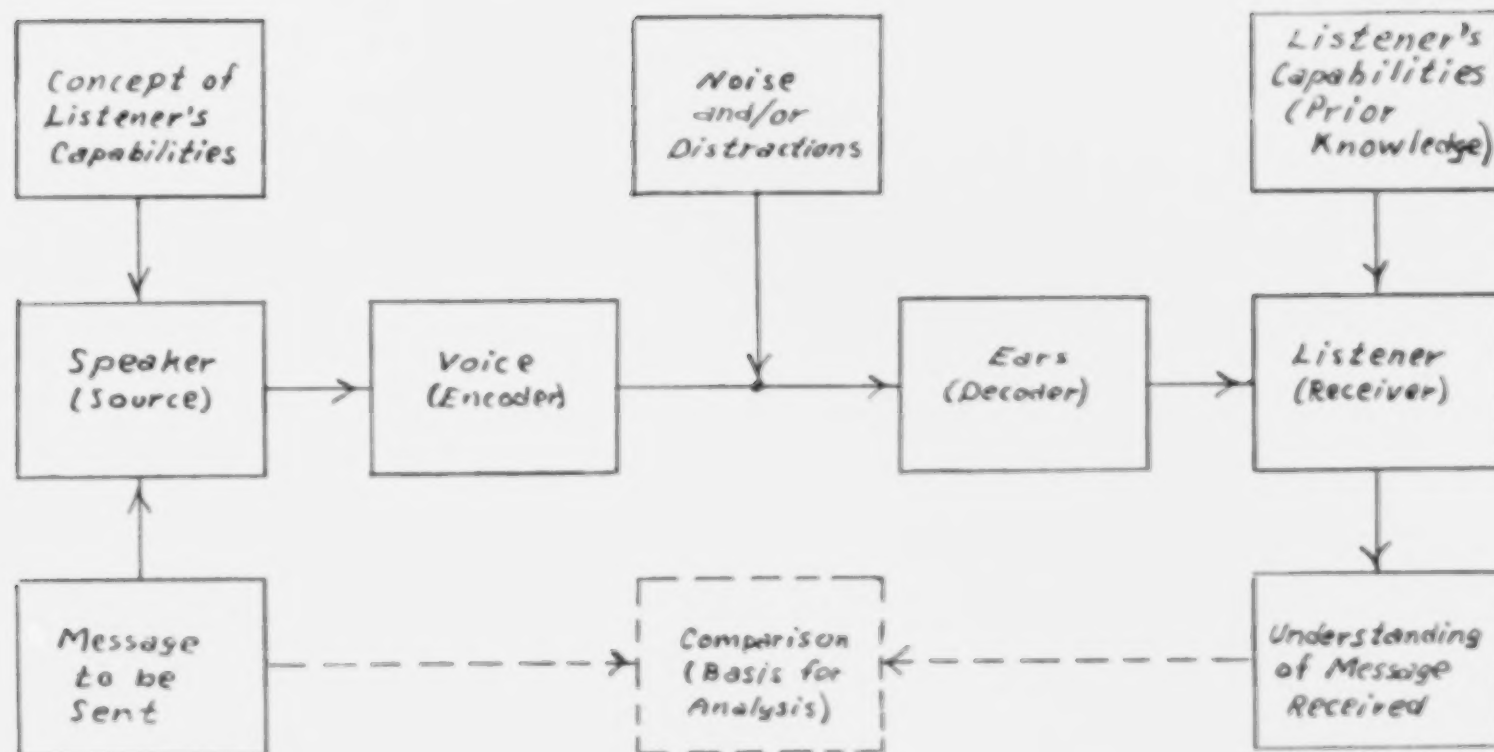


Fig.5 Application of Information Theory to Speech Communication

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